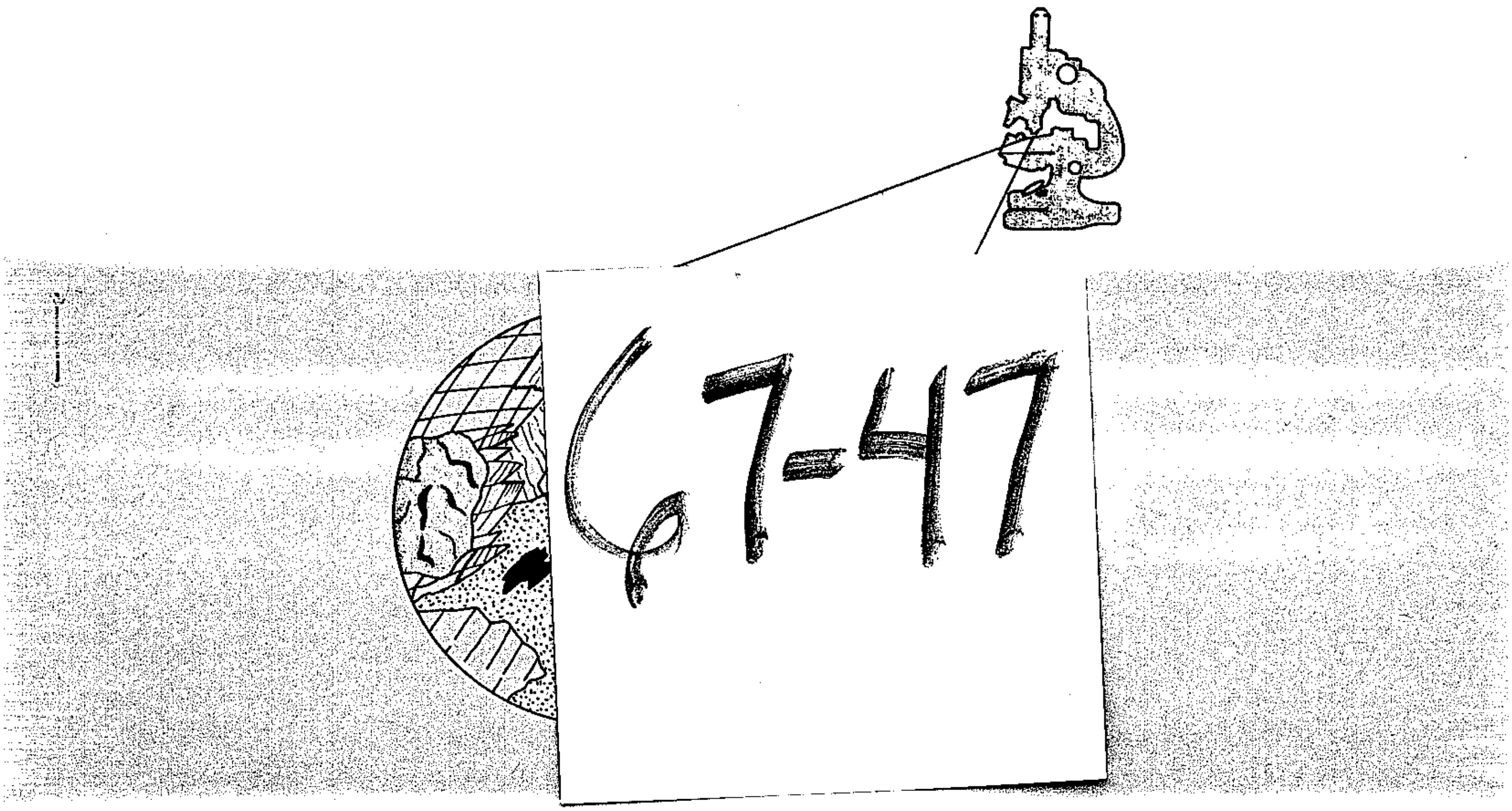
SECONDARY MINERAL ALTERATION



MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 632425

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State of California
Department of Public Works
Division of Highways
Materials and Research Department

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HPR-1(2) D-2-3
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Mr. J. C. Womack
State Highway Engineer
Division of Highways
Sacramento, California

Dear Sir:

Submitted for your consideration is:

FINAL REPORT

on

SECONDARY MINERAL ALTERATION

of

AGGREGATE BASE AND SUBBASE

Study made by .... Foundation Section
Under general direction of .... Travis Smith
Work supervised by .... M. L. McCauley
Report prepared by .... Duane D. Smith

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

Attach.

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Acknowledgments

The Engineering Geology Unit of the Foundation Section of the Materials and Research Department conducted this study of secondary mineral alteration. The work was begun under the 1964-65 Work Program HPR-1 (2) D-2-3 in cooperation with the U.S. Department of Commerce, Bureau of Public Roads.

Introduction and History

In August of 1961, this study was initiated after it was noted that there had been some failures of slope protection, base material and material that had been stockpiled for a few months.

Notable among the failures was an installation of riprap at Waddell Bluffs, 04-SCr-56-D, where after a period of six months granitic rock showed signs of severe rounding and disintegration. After a report entitled "Deterioration of Stone Riprap at Waddell Bluffs" was made, other areas were investigated and it was found that more rock types would be suspect, such as diabase, basalt, andesite, serpentine and some sandstones. Although these rock types in general met the requirements of the Standard Specifications it was apparent that when these rock types contain secondary minerals, methods of tests should be developed to recognize and restrict their use under certain climatic, construction, or processing conditions.

Approval for HPR participation in this study was made on October 14, 1964.

Results and Conclusions

Results obtained in this study point to a definite relationship between the presence of certain secondary minerals and poor performance records. Only a few cases of suspected base or subbase failures have been recorded, however. Their lack of occurrence or detection may have been the result of several factors; adequate physical testing which has largely eliminated the use of potentially deleterious aggregates, cement treatment or the use of other compensative measures where borderline materials are used, and inability to separate or establish the actual cause of failure.

Inability to discern the cause of failure is exemplified by the Miossi Quarry study where ramp failure was believed to have been the result of one or more of three factors; poor quality base and subbase material, a structural section which was too thin, or heavy irrigation of the landscaped ramp slopes without benefit of underdrains.

Serviceability of a particular material can also be questionable. Physical test results obtained from the Ventura County Ledge Rock study were acceptable but borderline for Class 2 base. Seven of the 23 specimens studied by petrographic, X-ray and D.T.A. techniques contained montmorillonite in excess of 25 percent. In light of this fact and the poor performance exhibited on some of the Corps of Engineers' rock slope protection installations, the material was considered questionable.

As a result of this study the following general observations can be made:

1. Considerable petrographic, X-ray diffraction and differential thermal analyses on samples from various areas have been completed for this study.

2. Thin section projection is not readily adaptable to mineral estimation but can be useful for observation of textural relationships of an entire thin section as opposed to the restricted field of a microscope.

3. Scattergrams and a technique for their use has been developed which permits a very rapid estimation of mineral percentages using 35 mm photomicrographic slides. The technique is limited for the most part to coarse-grained crystalline rock studies.

4. The point counter method of estimation has been inexpensively adapted to our present equipment and has proven to be a highly useful tool with good reproducibility. A count of from 550 to 650 points can be made accurately within 30 to 35 minutes for most thin sections.

5. Good photomicrographic results have been obtained using our present equipment and has been an aid in understanding the complexity of secondary alteration.

6. Numerous difficulties have been experienced in obtaining good service records. It is concluded that a greater awareness by district materials personnel of the existence and purpose of this investigation would have been helpful in developing more service records of completed projects as well as timely information on future projects where questionable aggregates were considered for use. Additional service records and test data would have to be obtained so that a sound statistical analysis of alteration in relation to service could be made.

7. Test data for some of the materials sites studied has not been sufficient. A more extensive sampling and testing program would have been desirable for each materials site and installation to insure accurate representation of the materials involved.

8. Additional research should be done in the fields of zeolites and the alteration products of volcanic glass to determine their physical characteristics as related to engineering properties.

Some specific observations can also be made about the individual materials sites investigated:

1. Twenty of the 23 specimens of the Ventura County submarine volcanic study contained from 4 to 56% montmorillonite while only one specimen contained 3% of a kaolin clay mineral. Alteration of some of the feldspars to montmorillonite rather than a kaolin clay may be the result of emplacement of volcanic rocks in sea water where the necessary MgO is present. Should this observation be correct, all submarine volcanics considered for use in highway construction would be suspect of containing a montmorillonite clay mineral.

Volcanic glass and the alteration produce palagonite occurred in 8 of the volcanics and are a potential source of degradation and alkali reaction.

2. Results of a study of augite teschenite from the Vera Miossi Quarry indicated that progressive alteration of the teschenite leads to formation of montmorillonite at the expense of analcite and feldspar. Petrographic, X-ray and physical tests support the contention that material from this source should be limited to aggregate subbase.

3. Calcitic dolomite from the waste piles of the Kaiser Refractory Plant contained no detectable deleterious secondary alteration products. Physical test results were very good as well, suggesting that the material should perform well as aggregate subbase and possibly as base material if the grading requirements are met.

4. Degradation of the Toro Point sandstone after being crushed and stockpiled was attributed to a breakdown of the chlorite-sericite? matrix and an inherent tendency to part along planes of bedding.

Purpose

The purpose of this research project was to study through petrographic, X-ray, and differential thermal analysis (D. T. A.) rock that contain secondary minerals and which have exhibited structural weaknesses and a tendency to degrade.

Since the inception of the study, investigative efforts have been largely confined to material used for aggregate bases and subbases. The greatest emphasis has been placed on volcanic rocks, primarily because of their widespread use throughout California, and the abundance of secondary minerals frequently associated with them.

Survey of the Literature

A survey of the literature was made with particular emphasis on secondary mineral alteration as related to aggregate base materials. A few of the more important articles will be discussed below.

As early as 1955, an extensive investigation of base and surfacing material from several quarries and installations in Western Oregon was made by Lewis E. Scott*, Chief Geologist of the Oregon State Highway Department. All deposits examined were either submarine volcanics interbedded with sediments or intrusive dike rocks. Scott found that there is a direct relationship between the presence of secondary minerals and "surface failures" when aggregates from these sources were used. As a result of his study he concluded that "0 to 20 percent of secondary minerals in a fine aggregate will have little effect; 20 to 35 percent will produce some failures and borderline results; and 35 percent and above will almost certainly cause failures." No apparent distinction was made between different types of secondary minerals.

H. L. Day, in studying various basalts of Northern Idaho for the Idaho Department of Highways concluded that "there seems to be little doubt that the index of quality lies in the combined percentage of the mineral alteration products, kaolinite, smectite, iddingsite, chlorophaeite and palagonite." He found no evidence for futher alteration of in-place base material bur rather considered the alteration to have taken place prior to emplacement. A laboratory degradation test was derived which is a wet-abrasion process using a modified Deval apparatus. Day's findings were described in a progress report presented to the 41st Annual Meeting of the Highway Research Board in 1962.

*References cited in the text are listed at the end of the Appendix.

An excellent paper with a refreshing approach to weathering of basic igneous rocks in road foundations was published by H. H. Weinert of South Africa in 1964. A "Climatic N-value" was assigned for each local area studied which took into account the rainfall, evaporation, and temperature for that particular zone. Better performance for those weathered basic igneous rocks in areas with an N-value greater than 5 could be expected, according to Weinert, than in those with a lower value. A distinction was also made between the climatic environment of the quarry site and the environment at the installation. One interesting field test recommended for the determination of the stage of weathering employs luster, hardness and consistency, and the state of crystallization.

E. Nyoeger of Australia made a study of a basalt flow north of Melbourne in which he attempted to correlate the percentages of secondary minerals within a crushed base material with their liquid limit values. Results of the statistical work of this correlation published in 1964, suggested that there is no association between liquid limit and secondary mineral percentage on a linear basis and that they appear as independent variables. Nyoeger appears to concur with Scott's limits of secondary mineral percentages as related to the quality and performance of the base material.

Chemical and mineralogical transformations associated with the weathering of basic volcanic rocks was investigated in 1964 by D. C. Craig and F. C. Longhnan of New South Wales, Australia. They analyzed six profiles in an attempt to trace the sequence of mineralogical and chemical transformations associated with the weathering of basic volcanic rocks from the surface to the bottom of existing quarries.

Weathering of ferro-magnesium rich minerals and plagioclase in the volcanic rocks formed montmorillonite as exemplified in the lower portions of the profiles. They concluded that in near-surface horizons the montmorillonite was not stable and when subjected to intense leaching it apparently formed halloysite, kaolinite or a poorly crystalling montmorillonite. This conversion was accompanied by the release of magnesia and silica. Continued leaching apparently removed additional silica from the kaolinite in the near-surface horizons, resulting in the formation of bauxite minerals.

Alteration of orthopyroxene and olivine in basic volcanics and their resulting products was studied in 1958 by H. G. Wilshire of the University of Sidney, Sidney, Australia. Alteration products were identified by X-ray techniques and an attempt was made to integrate ideas concerning their mode of origin and relationships.

Description of Equipment Used and Techniques Employed

Various pieces of equipment were used in the investigation of secondary mineral alteration. A standard Spencer Polarizing Microscope was used for all thin section work. A six-unit Clay-Adams blood cell counter was used in conjunction with a point counter to determine mineral percentages. In conjunction with the microscope, Spencer photomicrographic equipment employing a 35 mm Kodak camera was utilized for taking the photomicrographs included in this report. Although color photomicrographs are far more useful in depicting minerals characterized by a certain color or occurrence, the cost is roughly ten times as great and therefore only black and white photos were used in this report.

A General Electric XRD-5 diffraction Unit was used to X-ray all samples reported. The samples were ground to pass either the 508 or 200 sieve and pressed into a briquette for analysis. A portion of the same powdered sample was used for differential thermal analysis with equipment composed of Lindberg ovens and Leeds and Northrup recording and control components.

Percentage Estimation Equipment and Techniques

General

X-ray diffraction analysis of an altered sample of rock is the best single technique used for the identification of clay minerals contained within it. Quantitative techniques using this tool are limited, however, and have not been developed to a high degree of accuracy. This department is currently conducting a research program in this field.

Differential thermal analyses of powdered rock samples were useful in the qualitative determinations of samples. No attempt was made to derive quantitative values by this method. A search was therefore conducted for a reliable method to accurately determine the percentages of various minerals, both primary and secondary, present in a sample under study.

Scattergrams

Two inch by two inch 35 millimeter photographic slides were prepared using minute black squares randomly scattered over their surface area. The area covered by the squares is directly proportional to the surface area of the slide. That portion of the slide covered by the squares represents 1, 3, 5, 10, 15 and 25 percent of the surface area respectively.

The scattergrams were projected on a screen alternately with colored photomicrographic slides of thin sections which had been studies microscopically. A direct visual comparison of the colored secondary minerals to various percentages represented by the scattergrams was made, resulting in a rapid mineral estimation with an accuracy of within 5% or less.

Two slide projectors can also be set up with parallel projection of a photomicrograph to one screen and a selected scattergram to a second screen located adjacent to it. Scattergram slides can then be changed until an area of black squares corresponds closely to the area represented by secondary mineralization on the photomicrograph.

Occasionally secondary minerals are found to be finely disseminated throughout a groundmass as opposed to partial or complete replacement of larger penocrysts. In these cases percentage estimations using scattergrams is of little value.

Thin Section Projection

A second method of percentage estimation was investigated by the projection of the actual thin section on a screen. To accomplish this, a plastic 35 mm photographic slide frame was modified by removing one side. The thin section was inserted into the frame and put into a standard slide projector equipped with a blower to remove excessive lamp heat thus preventing a softening of the cementing media used to attach the rock slice to the glass slide.

The objective of this method was to magnify the thin section by projection and then make a comparison of the section projection with the scattergrams. Color, however, was not transmitted to the screen except for some colored translucent minerals which gave a very faint coloring when projected. This method cannot be used for percentage estimation due to lack of color, but is a good means of studying textural relationships of the total slide.

Point Counter

Several point counters have been devised over the past years for thin section analysis. A search through the literature revealed a simple apparatus which was easily made by a slight modification of our existing Spencer mechanical stage. Small gears were attached to the knurled knobs, which, when turned, move the thin section across the field of the microscope.

Metal clips were attached to the stage and are in contact with the gears resulting in an audible click when the knob has been turned a distance equal to one tooth of the gear. Using this system of gears and clicks, a grid system of points, dependent upon the number of teeth on the two gears, was established. After a click was made, the mineral beneath the cross-hair of the microscope was identified and recorded on a Clay-Adams Six Unit Counter, a tabulator having 5 keys with 5 running totals and a cumulative total of all counts.

Analyses of the sections were made using this method, and the cumulative total of counts for each mineral were read at the completion of the grid system. Any number of points per grid can be obtained by changing the number of teeth and magnification of the microscope. F. Chayes, in his article "A Simple Point Counter for Thin-Section Analysis," published in Volume 34 of The American Mineralogist, suggests that for a standard thin section area of 1 inch by 3/4 inch, an analysis of 1400 points spaced at 0.3 mm in one direction and 1 mm in the other is satisfactory. H. H. Weinert in his bulletin on weathering of basic igneous rocks found that 500 or slightly more counts per thin section were satisfactory in obtaining an accurate percentage count.

It was found that using an eye piece of 10X and an objective of 10X for a total magnification of 100X in conjunction with two gears having 13 teeth each gave an average count of from 550 to 650 counts per thin section. A spacing of two clicks or approximately 1 mm between the rows counted (along the long axis of the section) gave the desired number of counts per thin section. Cracks, vesicles, and holes in the thin section produced during the grinding of the section were not counted. Dull zones attributed to an overlap of two primary minerals or a primary and secondary mineral were not counted.

In a limited number of cases some difficulties were experienced in working with extremely fine-grained volcanics, particularly when secondary alteration was evident as minutely disseminated specks in a very fine-grained groundmass. In such cases a separate tabulation of the percent of groundmass was made. An accurate total of secondary minerals therefore could not be made for that portion within the groundmass. Samples falling within this category therefore show a minimum percentage of secondary minerals recorded. The point counter was used extensively in the individual studies discussed below.

Individual Studies

Ventura County Ledge Rock

Several groups of rocks from the Los Angeles area have been forwarded to this department for petrographic analysis and X-ray diffraction in connection with their proposed use as base and subbase material. Although these potential source areas were not specifically considered at the inception of this study, they formed a group of volcanics which contained abundant secondary minerals and yet, in some instances met the requirements of the standard specifications for aggregate base and subbase.

The District 07 office in Los Angeles submitted seven samples of Ventura County Ledge Rock for complete physical testing. Laboratory numbers assigned to the samples are as follows:

Hawley Quarry	63-2184
Schmidt Quarry	63-2185
Malibu Lake Streambed	63-2186
Conejo Mtns. Corps of Engr. No. Quarry	63-2187
So. Mtns. Creek Bed	63-2188
Triunfo Creek	63-2189
Conejo Mtns. Corps of Engr. So. Quarry	63-2190

An extensive physical testing program was run on the above samples (see Table 1). Routine tests for base material include durability for both the coarse and fine fractions, R-value and sand equivalent. In addition to these tests mentioned, special tests consisting of the Los Angeles Rattler, Sodium Sulfate Soundness, Apparent Specific Gravity, Absorption, Plasticity Index, Wet Shot and a 10-cycle Wet-Dry test were run on either the coarse or fine fraction or both. The Wet Shot test is no longer used by the California Division of Highways as a required test for aggregate base, but was run as a correlation with aggregate base tested in the past.

All seven samples failed the Standard Specifications for rock slope protection and Class 1 aggregate base, but passed requirements for Class 2 base even though the results were borderline in some cases. An exception to this was aggregate from Triunfo Creek which had a fine durability index of 31 and therefore failed to pass even the Class 2 requirements. In addition to the physical testing program, a complete petrographic, D.T.A., and X-ray diffraction study was made. From the seven samples received, 23 specimens were selected for examination on a basis of rock types and degrees of weathering represented.

Methods employed were petrographic examination of thin sections and X-ray diffraction and differential thermal analysis of powdered samples. Rock types within this assemblage of submarine volcanics included rhyolitic tuff, rhyolite, trachyte, volcanic glass, vitric and lithic tuff, andesite, olivine basalt and hematite-rich vesicular basalt. Listed in Table 2 are estimated percentages of secondary minerals identified in the samples. The percentages were originally based on a comparison of the X-ray records with established standard charts. At a later date the percentages of individual minerals, both primary and secondary were redetermined, using the point counter method discussed in this report. The original estimates based on standard X-ray charts were found to be consistently higher than those of the point counter for the clay mineral montmorillonite but in general agreement for the other minerals. A possible answer to this discrepancy may lie in the degree of crystallinity of the montmorillonite. Montmorillonite in the rocks studied appeared as shard-like or aggregate masses of crystals when viewed through the petrographic microscope. Corresponding X-ray peaks were strikingly narrow and pointed as opposed to broad, relatively flat peaks commonly characteristic of montomorillonite in soil samples.

The source areas for these tested materials were visited on July 6, 7, and 8, 1964. Samples for additional thin sections were collected and service records were established which included photographs and descriptions of the quarry sites. Installations utilizing rock from these sources were also examined and consisted entirely of rock slope protection projects constructed by the Corps of Engineers and the California Division of Highways along the coastal highway and in small boat harbors from Ventura south to Santa Monica.

Hawley Quarry and Installations

Two of the more interesting installations using volcanics from the Ventura County quarries are the Ventura County Small Boat Harbor located at Silver Strand and the Santa Clara River Levees, both Corps of Engineers projects. The first installation was constructed of Hawley Quarry rhyolitic volcanic agglomerate in 1956 (photo 19). Six to eight-foot diameter boulders placed around the perimeter of the harbor exhibit extensive weathering. The weathering, however, is largely confined to clasts contained within the matrix of the volcanic agglomerate (see Photo 20). Occasional cracks were noted in the fine-grained matrix where large clasts had weathered out suggesting the formation of an expansive product of weathering within a confined area or a weakness of the rock produced by the void. The former possibility was confirmed when X-ray and thin section analysis revealed a concentration of montmorillonite within the older clasts. Montmorillonite percentages ranged from 14 to 28 percent for the original samples sent in by the District (see Table 2).

Rock slope protection from the same source was used along Road 07-Ven-101 at La Jolla Canyon Beach a few miles south of Point Mugu. This installation was also made in 1956 and is weathered similarly to that of the Ventura County Small Boat Harbor. Rounding of the boulders with less differential weathering was noted, however, where wave action was active on the beach (photos 21 and 22).

Conejo Mtns. Corps of Engr. Quarry and Installations

Installation of rock slope protection from Conejo Creek North and South quarries along the Santa Clara River levees from Sta. 353 to 491 was begun in October of 1959 by the Corps of Engineers. Production from the two adjacent quarries was stopped on March 12, 1960, a period of approximately six months, because of total disintegration to "mud" of the emplaced material. Other sources were used and a blanket of new rock was placed over the poor material.

Samples from the North and South quarries were included in the group from Ventura County as possible sources of base material, and are shown on Table 2 as 63-2187 and 63-2190. Material from the North Quarry contained from 15 to 34 percent montmorillonite and was frequently rich in hematite. Samples from the South Quarry ranged from 6 to 8 percent montmorillonite and for the most part contained a large percentage of devitrified glass.

Photomicrographs 1 through 12, included in Appendix 1, illustrate various types and degrees of alteration and replacement which have taken place in the suite or rocks received for the Ventura ledge rock study.

During this investigation of submarine volcanics it was noted on several thin sections that microphenocrysts of feldspar had been partially or completely replaced by minute pale green shard-like crystals. These crystals have been identified as montmorillonite, with supporting identification by X-ray diffraction. Kaolin has a general chemical formula of $Al_2O_3 \cdot 2\,SiO_2 \cdot 2H_2O$ while a general formula for montmorillonite consists of $5\,Al_2O_3 \cdot\ 2MgO \cdot 24SiO_2 \cdot 6H_2O$. It is thought at this time that the MgO present in the montmorillonite of the submarine volcanics but absent in kaolin could possibly be largely derived from sea water resulting in the feldspar alteration to montmorillonite rather than a kaolin clay mineral. Some of the MgO could have been supplied by alteration of the ferro-magnesium minerals but as a group the rocks were of an acid type with low percentages of ferro-magnesium minerals. Only one sample of the 23 Ventura County volcanics contained kaolin of an estimated3% while 20 samples contained an estimated 4-56% montmorillonite. Should this observation be found correct, all submarine volcanics considered for use in highway construction would be suspect of containing a montmorillonite clay mineral.

Eight of the 23 volcanic samples contained devitrified volcanic glass and/or palagonite. Alteration of glass to palagonite with the accompanying hydration may result in swelling and may possibly be a cause of degradation in itself. Construction materials containing volcanic glass or its altered product therefore are undesirable for highway construction purposes because of the potential degradation and alkali reaction properties.

Petrographic, X-ray, and D. T. A. studies on the 23 specimens indicate extensive alteration and abundant secondary minerals in most of the samples studied. Good correlation was noted between X-ray diffraction, D. T. A., and thin section studies. Correlation between these three studies and the physical test results, however, were inconclusive. Samples with poor physical test results did not necessarily have consistently high secondary mineral percentages nor was the reverse necessarily true.

An explanation of this poor correlation probably lies in the fact that three or four specimens were selected for study from each sample based on the different rock types and degrees of weathering evident in the sample. The ratio of each selected component to the actual quantity present in the sample is unknown, however.

Vera Miossi Quarry

On April 22, 1965, the Vera Miossi Quarry located approximately one mile north of San Luis Obispo on Road 05-SLO-101 was visited, and samples were collected for complete testing. This quarry has been used by District 05 as a source of cement treated base and subbase in the past.

Material at the quarry site appears highly altered and of very poor quality. Several faces have been worked in the past, the most recent being the south face which appears to be in better quality rock than the others. District personnel report that this source has been used for some time and has proven satisfactory for subbase but requires cement treatment when used as aggregate base. It has been used as cement treated base on a few county jobs involving FAS funds.

One project of particular interest is a 3 mile section of freeway, Road 05-SLO-101, through San Luis Obispo which was completed in 1954. Cement treated base and subbase from the Miossi site was used throughout the project for both the through-lanes and overcrossing ramps. The ramps failed after 10 years service. The pavement was characterized by an alligator pattern. District personnel believe there may be three contributing causes to the failure; poor quality base and subbase material, a structural section which is too thin, and heavy irrigation of the landscaped ramp slopes without the benefit of underdrains. Through-lanes, constructed with similar material have been in service since 1954 and appear to be in good condition.

Petrographic, X-ray, and D. T. A. analyses were made on the samples collected in April of 1965, from the quarry. The best quality material obtainable in the quarry, by visual inspection, is represented by sample 65-2054. Sample 65-2055 represents the "pit run" material from the face most recently mined for aggregate production.

Results of the study (see Table 3) indicate that progressive alteration of the augite teschenite in this area leads to the formation of montmorillonite at the expense of the analcite and feldspar. It should be noted that there is nearly twice the amount of montmorillonite in the "pit run" sample as in the selective one. Physical test results were very poor, except for the SE, limiting use to aggregate subbase.

Kaiser Refractory Plant Waste Products

In November of 1965, a sample of the waste product from the Kaiser Refractory Plant near Salinas, California, was received from the resident engineer of a job under construction in that area. The material was to be used as Class 2 aggregate subbase for a 4 mile section of Road 05-Mon-101. Reports received by the engineer of expansive properties and high absorption experienced on other, unidentified projects, was not substantiated by preliminary and control sampling and testing.

A testing program to include petrographic, X-ray and D. T. A. analyses was established to clarify the situation and identify any deleterious minerals or properties which might be present. The sample was found to be a white, hard to moderately hard, medium to coarsely crystalline calcitic dolomite. Euhedral crystals of dolomite and calcite with a few minute crystals of quartz and widely disseminated specks of a clay or clay-like material was noted in the thin section.

X-ray diffraction indicated the presence of dolomite, calcite, quartz and a minor amount of feldspar. Feldspar was not noted in the thin section. Test results shown on Table 4 are well within specifications for aggregate base and subbase. No deleterious minerals or properties could be found and the material was considered to be sound. The material was used as Class 2 subbase on the project and has shown no signs of distress to date.

Toro Point Sandstone

During the construction of Road 05-SLO-101 between Morro Bay and Cayucos, in 1962, the contractor attempted to use sandstone from a roadway excavation at Toro Point for the production of aggregate base. The material met the specification requirements for aggregate base during the preliminary testing but had borderline SE values. In addition, a durability test was run even though the test at that time was new and not part of the specifications. Durability test values were poor, ranging from 6 to 24.

Approximately 10,000 tons of the sandstone were crushed, processed and stockpiled in January of 1962, for use at a later date. Control tests taken during the production period were satisfactory but again had a low SE value. By April of the same year, the material in the stockpile, which had been subjected to the winter rains, showed definite evidence of degradation with pronounced rounding and parting along planes of weakness. The sandstone was subsequently used only as the lower 6 inches of aggregate subbase for a 2000 ft. section from North Morro Bay Undercrossing to Morro Creek Bridge. The typical section consisted of 1.00 ft. Class 2 aggregate subbase, .66 inches Class 2 aggregate base, 3.0 inches plant mix and .08 inches open graded. The project was approved as finished in October of 1963.

Examination on April 21, 1965, of the benched cut face from which the sandstone was taken showed some breakdown with numerous partings along planes of weakness. Most of the sandstone could be easily shattered with one blow of a hammer. Samples were collected at this time for laboratory testing including petrographic, X-ray and differential thermal analysis. The section of pavement where the sandstone was used showed no evidence of distress. Test results of the collected samples are shown in Table 4. Degradation of the sandstone was attributed to a breakdown of the chlorite-sericite matrix binding the individual sand grains and an inherent tendency to part along bedding planes. No clay minerals were identified by X-ray diffraction.

Service Records

Service records for the aggregate base and subbase studies have been difficult to establish. A materials site may have been a source of base or subbase over a period of years but information on a specific contract or job location where the aggregate has been used may be unknown or questionable. In other cases the job location may be known but the class or type of aggregate used on that job is unknown. Two or three sources of material are commonly used on a major project and it is frequently difficult to establish on which portion of the project a particular source has been used. In addition, the testing procedures and specification requirements have changed through the years, for example the Wet Shot Rattler Test has been replaced by the Durability Factor and P.I.'s are no longer required, so that comparison of the original test results with the present requirements are difficult.

Information concerning base failures has been obtained after corrective measures have been taken, thus eliminating first hand observation and sampling of the original material used. An awareness by district personnel of the existence and purpose of this investigation has been fruitful in establishing the limited number of service records obtained in the study.

APPENDIX

List of Photographs and Photomicrographs

1. Vesicular volcanic altered to goethite and montmorillonite.
2. Dolomite amygdules in groundmass of hematite.
3. Fractured plagioclase in porphyritic trachyte.
4. Spherulitic chalcedony with montmorillonite-filled fractures.
5. Glassy volcanic with chalcedony, montmorillonite and cryptocrystalline quartz. X-nic.
6. Same as photo 5, but with plain polarized light.
7. Altered volcanic glass with spherulites.
8. Hematite-rich vesicular volcanic with chalcedony.
9. Crystalline montmorillonite and corroded feldspar.
10. Complete replacement of relict amphibole by montmorillonite.
11. Olivine altered to iddingsite in basalt.
12. Relict pyroxene crystal altered to montmorillonite.
13. Chloritized biotite in sandstone.
14. Toro Point sandstone.
15. Analcite largely altered to crystalline montmorillonite.
16. Chloritized augite in radiating pattern.
17. Altered analcite and augite.
18. Veinlet of weathered dolomite in calcilic dolomite.
19. Installation of volcanic agglomerate from Hawley Quarry.
20. Differential weathering of agglomerate.
21. La Jolla Canyon Beach installation.
22. Rounding of agglomerate by wave action.

Mineral Symbols

A	-	Augite
An	-	Analcite
B	-	Biotite
C	-	Calcite
Cd	-	Chalcedony
Ch	-	Chlorite
Ct	-	Chert
D	-	Dolomite
F	-	Feldspar
G	-	Goethite
Gl	-	Glass
H	-	Hematite
Hb	-	Hornblende
I	-	Ilmenite
Id	-	Iddingsite
K	-	Kaolinite
M	-	Magnetite
Mt	-	Montmorillonite
O	-	Olivine
P	-	Palagonite
Q	-	Quartz
Sh	-	Shale

REFERENCES

Chayes, F., "A Simple Point Counter for Thin-Section Analysis." American Mineralogist, Vol. 34, 1949, p. 1-9.

Craig, D. C., and Loughnan, F. C., "Chemical and Mineralogical Transformations Accompanying the Weathering of Basic Volcanic Rocks from New South Wales." Australian Journal of Soil Research, Vol. 2, 1964, p. 218-234.

Day, H. L., "A Progress Report on Studies of Degrading Basalt Aggregate Bases." Highway Research Board, Bull. 344, 1962, p. 8-16.

Nyoeger, E., "Petrological Investigation into the Secondary Minerals of an Older Basalt Flow North of Melbourne," Australian Road Research Board, Vol. 2., 1964, p. 1-10.

Scott, Lewis E., "Secondary Minerals in Rock as a Cause of Pavement and Base Failure." Highway Research Board Proc., Vol. 34, 1955, p. 412-417.

Weinert, W. W., "Basic Igneous Rocks in Road Foundations," Council for Scientific and Industrial Research, Report 218, 1964, p. 1-47.

Wilshire, H. G., "Alteration of Olivine and Orthopyroxene in Basic Lavas and Shallow Intrusions." American Mineralogist, Vol. 43, 1958, p. 121-147.

TABLE I
RESULTS OF PHYSICAL TESTS
ON
VENTURA COUNTY VOLCANIC AGGREGATES

Sample No.	Durability		LART		WST	$Na_2 So_4$		App Sp.Gr		Abs	Wet-Dry Loss			R-Value	SE	PI
	Dc	Df	100R	500R		C*	E	C	F	C	3 Cyc	6 Cyc	10 Cyc			
63-2184 Hawley Quarry	51	35	6	22	20	10.8	18.4	2.21	2.64	6.5	3.9	5.0	5.8	84	36	3
63-2185 Schmidt Quarry	56	48	6	23	20	6.3	12.6	2.22	2.71	6.0	3.3	4.3	5.2	84	43	NP
63-2186 Malibu Lk. Stream Bed	54	35	4	32	29	23.4	18.0	2.24	2.60	5.5	1.0	1.8	2.7	82	49	NP
63-2187 C of E No. Quarry	49	35	9	27	34	20.2	20.2	2.38	2.71	5.1	6.2	8.2	10.7	82	50	NP
63-2188 Creek Bed So. Mtns.	52	39	6	24	24	10.4	19.2	2.35	2.64	4.3	4.1	5.0	5.9	83	43	NP
63-2189 Triunfo Crk.	52	31	6	29	26	16.3	19.7	2.27	2.56	4.9	3.6	4.4	5.3	81	40	NP
63-2190 C of E So. Quarry	59	35	10	37	33	14.9	22.2	2.31	2.65	4.5	2.4	3.3	4.2	81	52	NP

* Coarse Soundness calculated using 50% 3/4" x 1/2", 20% 1/2" x 3/8" and 30% x No.4.

TABLE 2
RESULTS OF PETROGRAPHIC, D.T.A. AND X-RAY ANALYSES
ON
VENTURA COUNTY VOLCANIC AGGREGATES

Percentage of Secondary Minerals Present By Point Counter

Sample	Montmor-illonite	Kaolin	Chlorite	Iddingsite	Chalcedony	Vermiculite	Dolomite	Calcite	Cristobalite	Hematite	Goethite	Devitrified Glass and Palagonite
63-2184 #1	14											
63-2184 #2	28											
63-2185 #1	16											
63-2185 #2	25											
63-2186 #1	11				T						86	
63-2186 #2							28			63		
63-2186 #3	9								T			
63-2186 #4	6				13			6				50
63-2186 #5		3				T						95
63-2187 #1	26											
63-2187 #2	15				14					59		
63-2187 #3	34											
63-2188 #1	15									2		
63-2188 #2			5									10
63-2188 #3	9				1			T		T		
63-2188 #4	4			8								13
63-2189 #1	33											9
63-2189 #2	30				6							
63-2189 #3	8				5							
63-2189 #4	56				T			T				8
63-2190 #1	6											57
63-2190 #2	8								T			55
63-2190 #3	18			T								

T - indicates trace of mineral present.

TABLE 3

VERA MIOSSI QUARRY – SAN LUIS OBISPO
RESULTS OF PETROGRAPHIC, D.T.A. AND X-RAY ANALYSES

Mineral Percentage By Point Counter Method

	Sample	Montmorillonite	Chlorite	Analcite	Calcite	Feldspar	Augite	Ilmenite
*	65-2054	27	1	6	3	55	6	2
**	65-2055	51	4	0	2	35	6	2

Physical Test Results

Sample	R-Value	SE	Fine Dur.	Coarse Dur.
65-2054	81	76	33	47
65-2055	77	76	29	20

* 65-2054 Representative sample of best material in quarry by visual inspection.
** 65-2055 Representative sample of "Pit Run" material.

TABLE 4
TORO POINT SANDSTONE
RESULTS OF PETROGRAPHIC, D.T.A. AND X-RAY ANALYSES

Mineral Percentage By Point Counter Method

	Quartz	Feldspar	Matrix Chlorite-Sericite?	Chlorite	Chert	Shale	Calcite	Biotite	Augite
TORO POINT 65-2053	36	21	32	6	3	1	1	T	T

Mineral Percentage By X-Ray Standard Charts

	Dolomite	Calcite	Quartz	Feldspar
KAISER 65-4384	70	30	T	T

Physical Test Results

	R-Value	SE	Fine Dur.	Coarse Dur.	%p 200
TORO POINT 65-2053	79	37	24	6	14
Kaiser 65-4384	82	56	73	64	12

Photo 1 - Malibu Lake Streambed 63-2186 #1 X 100
Vesicular volcanic altered to geothite
(dark mass). Vesicle rims lined with
montmorillonite.

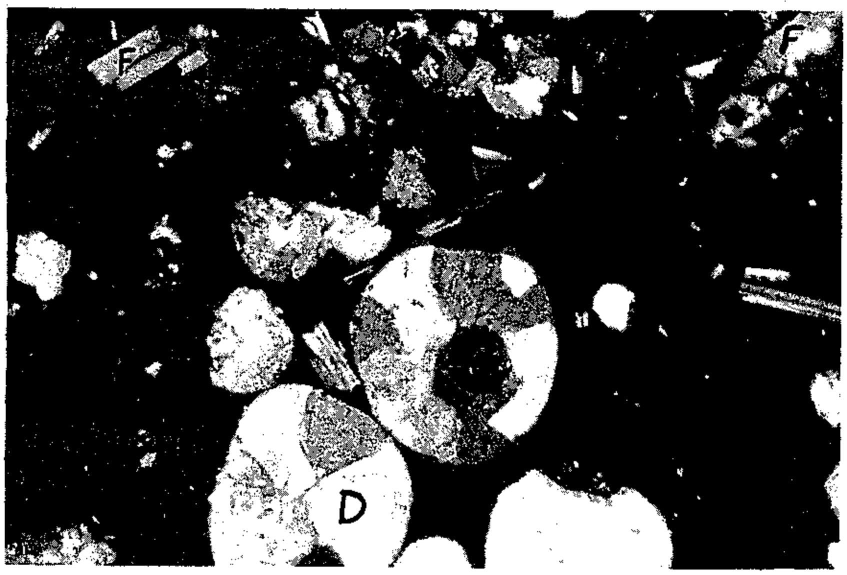

Photo 2 - Malibu Lake Streambed 63-2186 #2 X 100
Dolomite amygdules in groundmass of
hematite. Note scattered feldspar laths.

Photo 3 - Malibu Lake Streambed 63-2186 #4 X 100
Fractured plagioclase lath in porphyritic trachyte.

Photo 4 - Malibu Lake Streambed 63-2186 #4 X 100
Spherulitic chalcedony with montmorillonite along fractures.

Photo 5 - Malibu Lake Streambed 63-2186 #4 X 100
Amygdules consisting of a rim of sperulitic chalcedony with a core of cryptocrystalline quartz. Note dark glassy groundmass and relict amphibole altered to chalcedony with montmorillonite-filled fractures. X-Nic.

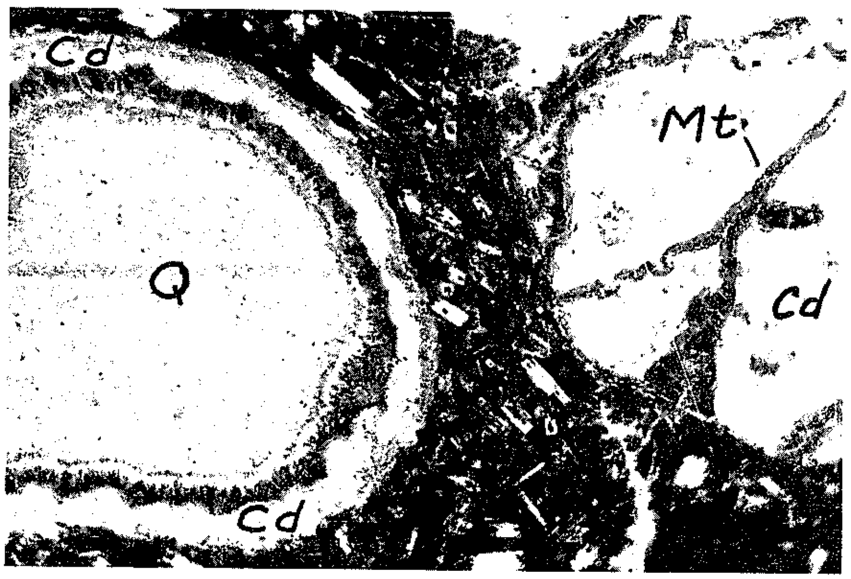

Photo 6 - Same as above but in plain polarized light.

Photo 7 - Malibu Lake Streambed 63-2186 #5 X 100 Volcanic glass with spherulites, largely altered to palagonite. Montmorillonite in upper right hand corner.

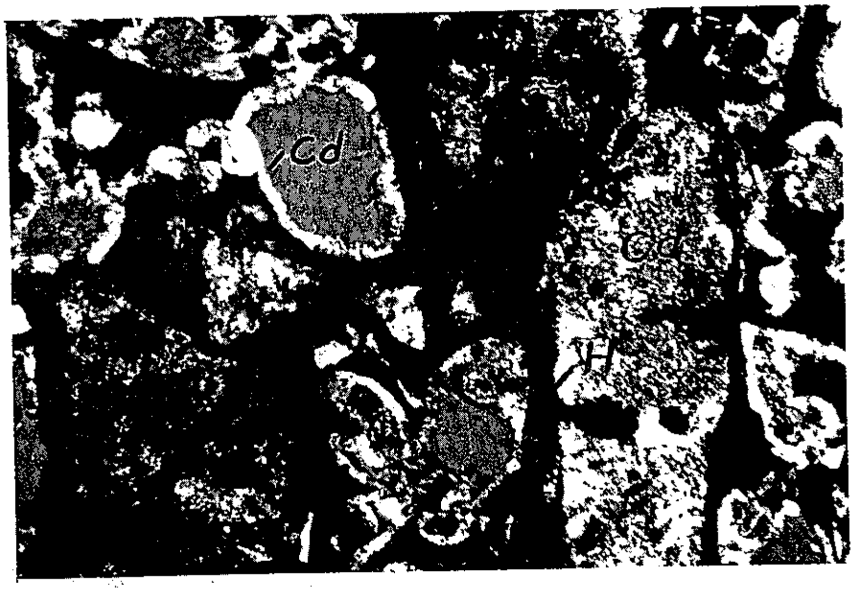

Photo 8 - Conejo Mtns. Corps of Engineers No. Quarry 63-2187 #2 X 100 Hematite-rich vesicular volcanic. Amygdules and vesicle linings of chalcedony.

Photo 9 - South Mtns. Creek Bed 63-2188 #1 X 100
Crystalline montmorillonite and corroded feldspar.

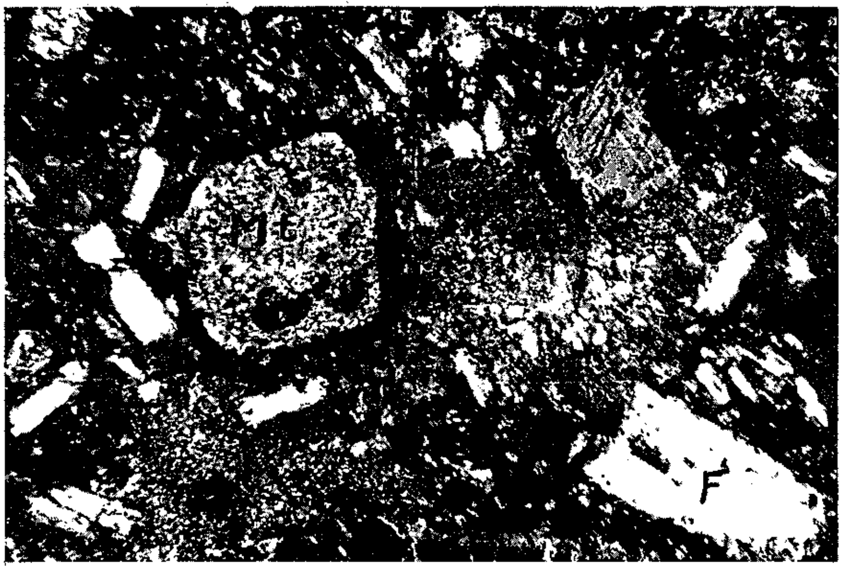

Photo 10 - South Mtns. Creek Bed 63-2188 #1 X 100
Complete replacement of relict amphibole by crystalline montmorillonite.

Photo 11 - South Mtns. Creek Bed 63-2188 #4 X 100
Olivine altered to iddingsite in basalt.

Photo 12 - Triunfo Creek 63-2189 #2 X 100
Relict pyroxene crystal altered to montmorillonite. Dark glassy groundmass.

Photo 13 - Toro Point Sandstone 65-2053 X 100
Chloritized biotite between two large quartz grains.

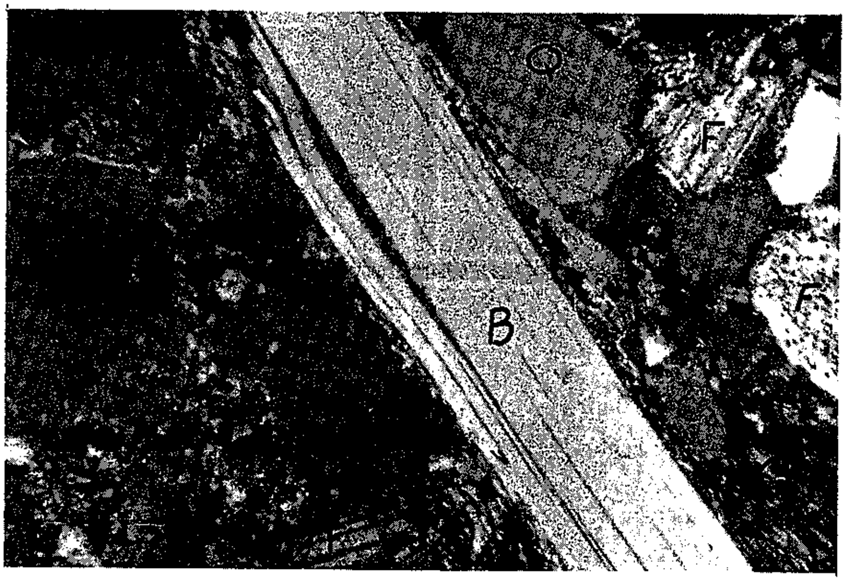

Photo 14 - Toro Point Sandstone 65-2053 X 100
Biotite, quartz, feldspar, magnetite and shale in chlorite-sericite? matrix.

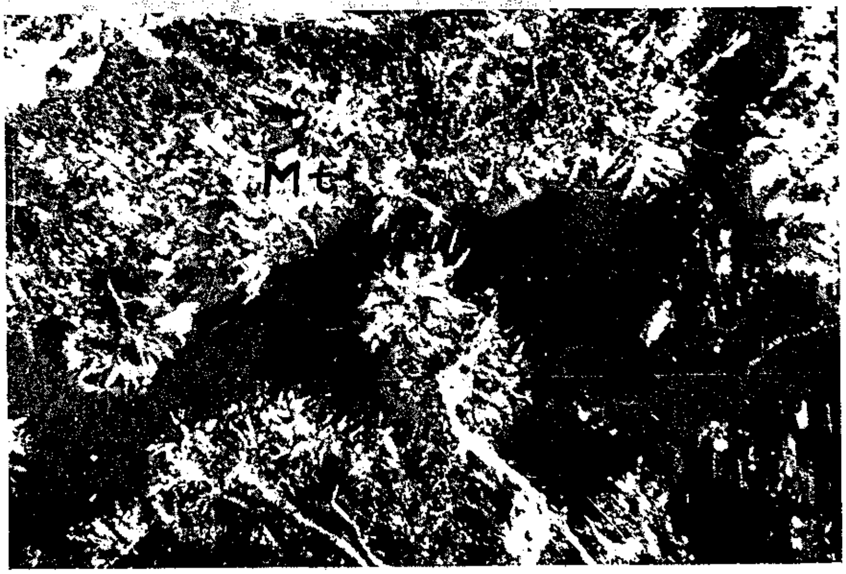

Photo 15 - Vera Miosi Quarry 65-2054 X 100
Analcite largely altered to crystalline montmorillonite.

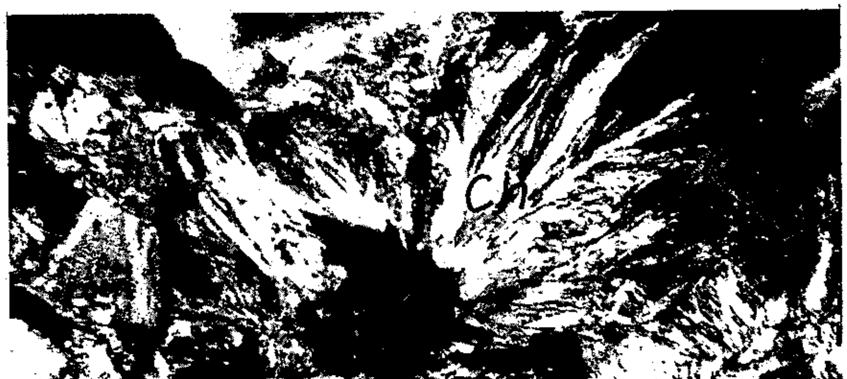

Photo 16 - Vera Miosi Quarry 65-2055 X 100
Chloritized augite in radiating pattern.

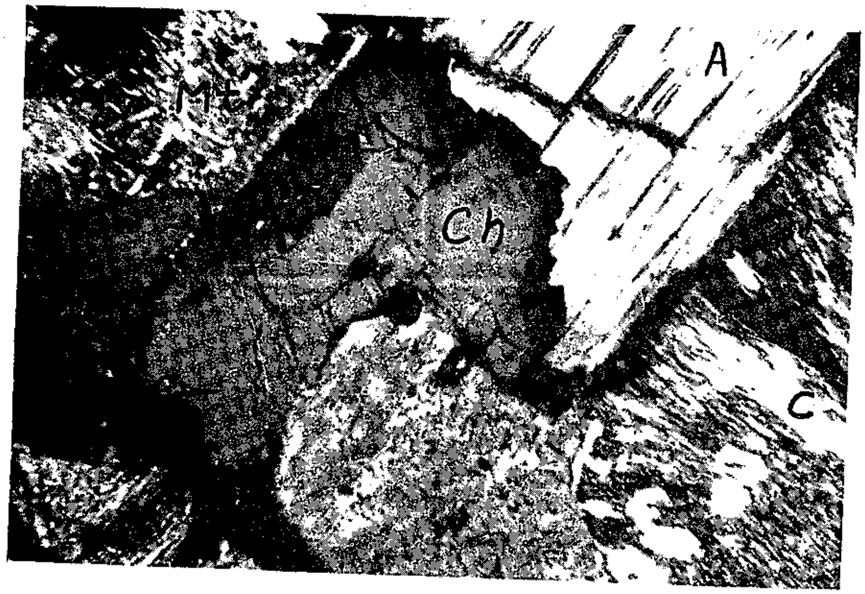

Photo 17 - Vera Miosi Quarry 65-2055 X 100
Chloritized augite and analcite
partially altered to montmorillonite.

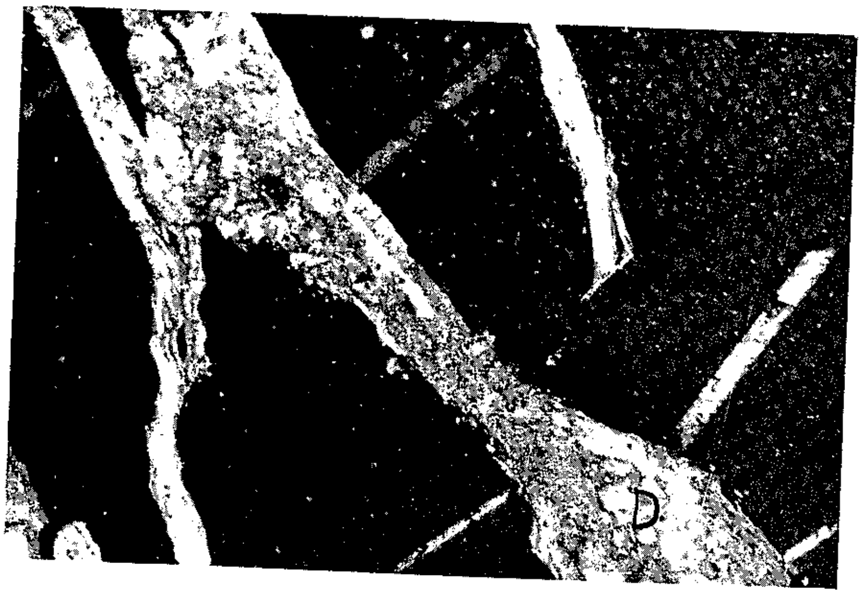

Photo 18 - Kaiser Refractory Plant waste pile
65-4384 X 100 Veinlet of weathered
dolomite in calcitic dolomite.

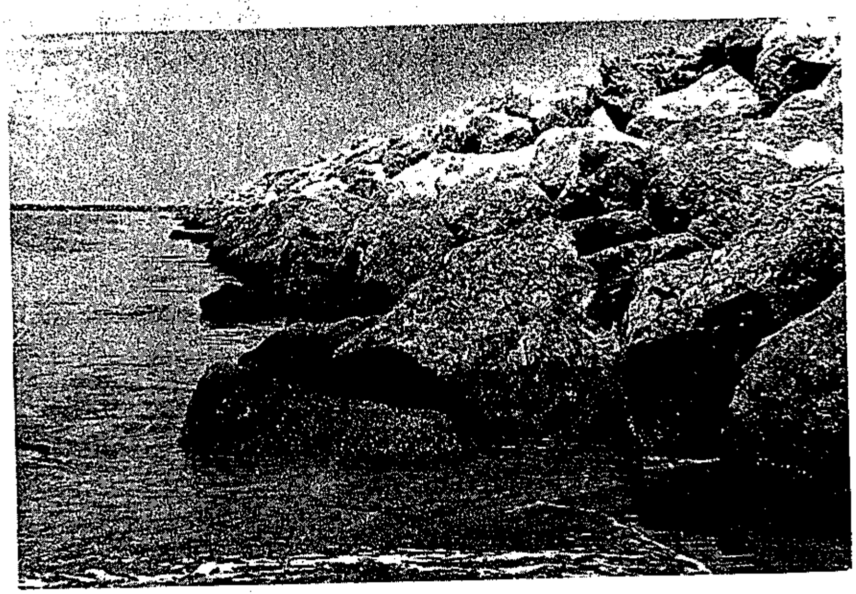

Photo 19 - Ventura County Small Boat Harbor at Silver Strand. Volcanic agglomerate from Hawley Quarry.

Photo 20 - Close-up of boulders in Photo 19. Note well defined weathering of clasts from the agglomerate.

Photo 21 - Volcanic agglomerate from Hawley Quarry used as rock slope protection on La Jolla Canyon Beach. Note differential weathering.

Photo 22 - Similar source and rock type as in Photo 21, but exposed to wave action. Note rounding, less differential weathering.